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Gene Avery
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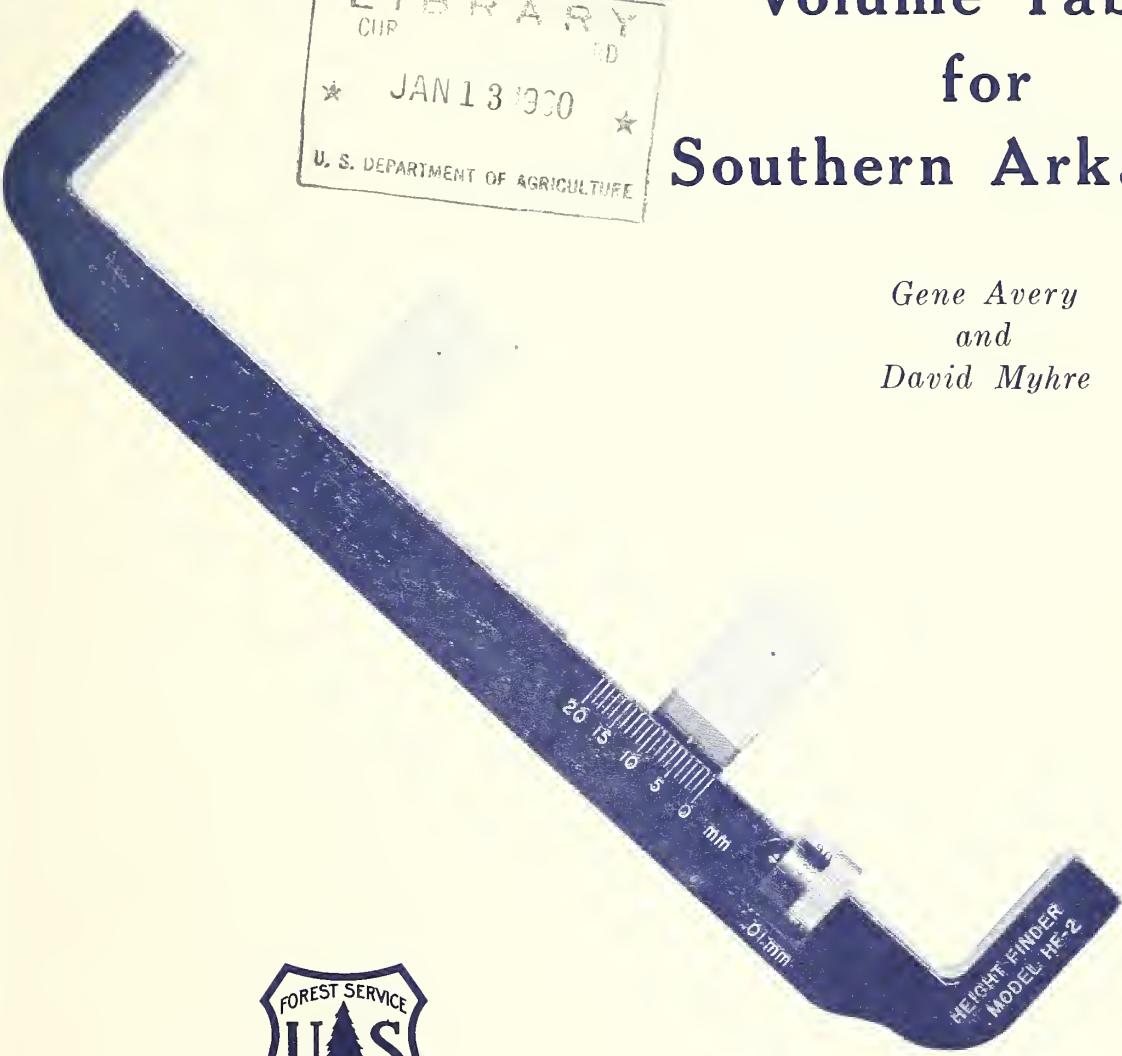

SOUTHERN FOREST EXPERIMENT STATION
Philip A. Briegleb, Director
Forest Service, U.S. Department of Agriculture

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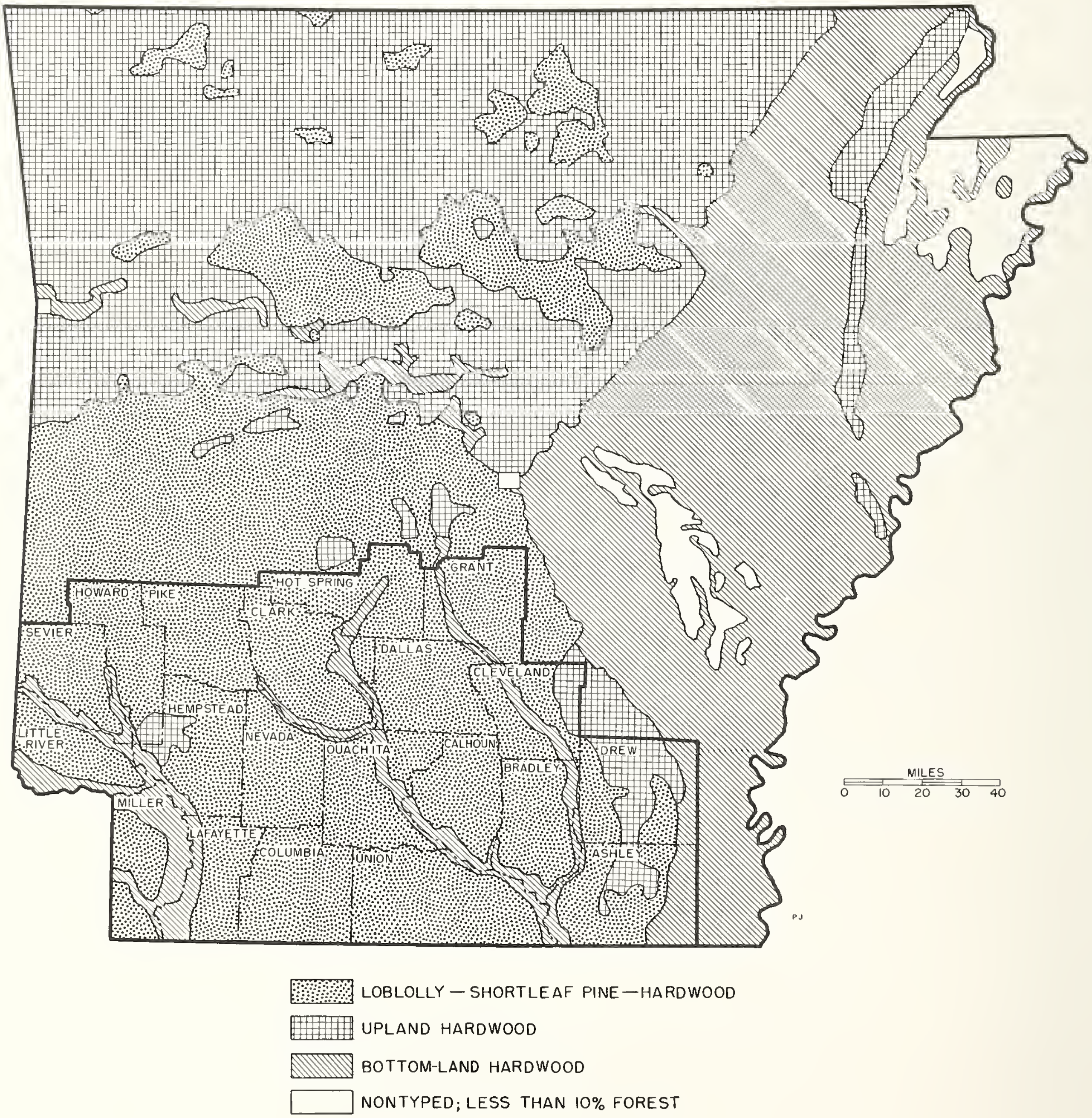

Figure 1.—*Generalized forest type map of Arkansas, showing the 20 counties covered by this study.*

Composite Aerial Volume Table for Southern Arkansas

Gene Avery and David Myhre [1]

Aerial photo volume tables are useful for making direct estimates of gross timber volumes, for preparing forest maps based on stand-size classes, for planning extensive forest inventories, and for reducing the intensity or cost of field work in photo-controlled ground cruises (**3**).[2] The initiation of the third Forest Survey of Arkansas in 1958 presented an opportunity to collect special data to construct and evaluate an aerial stand-volume table for making direct estimates of gross timber volume in the southern part of the State (fig. 1).

In the interests of statistical accuracy, aerial stand-volume tables are ordinarily constructed for a single tree species or a group of similar species. For example, tables have been prepared for upland oaks in Pennsylvania (**4**), Douglas-fir in Oregon (**10**), and Rocky Mountain conifers (**7**). This refinement has obvious advantages when forest types can be reliably differentiated on aerial photographs, but its importance is lessened when stand mixtures cannot be consistently classified.

In southern Arkansas, it was found that southern pines and hardwoods could not be adequately separated on the aerial photographs obtainable from the U. S. Department of Agriculture—9- by 9-inch prints, at a scale of 1:20,000 made from panchromatic film exposed with a minus blue filter. Although pine timber predominates, many stands are composed of pine-hardwood mixtures that exhibit minimal tonal contrast on panchromatic prints. Because of the difficulty of separating these species-groups for making photo measurements, it was decided that a composite table should be compiled for this area. The feasibility of constructing and using an aerial volume table for both pines and hardwoods had been previously demonstrated in northeast Mississippi (**2**).

CONSTRUCTION PROCEDURE

Every fourth Forest Survey location in each of 20 counties was mechanically selected for analysis. This result was a total of 304 paired point-sample locations[3] arranged on a 6- by 6-mile grid pattern. After elimination of stands that had been cut between the dates of photography and field measurement, 216 locations remained for interpretation.

One-acre circular plots were scribed on the 216 stereo pairs of photographs to exactly encompass the two point-samples at each Forest Survey location. Two photo interpreters measured, on each location, the average total height of the three tallest trees, average diameter of the three largest crowns, and the crown closure percent. The two sets of photo measurements for each location were then averaged for use in the statistical analysis.

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[1] The authors, members of the U. S. Forest Service, are currently located at the Southeastern Forest Experiment Station, Asheville, North Carolina, and the Southern Forest Experiment Station, New Orleans, Louisiana, respectively.

[2] Bold face numbers in parentheses refer to Literature Cited, p. 9.

[3] In the Forest Survey of Arkansas sample trees were selected from two points located 117.75 feet apart; they were chosen with a prism having a basal area factor of 10.

Total heights of the three tallest trees were also determined on the ground for each of the 216 locations. These data, along with tree tallies for computing volumes, were obtained by Forest Survey field personnel.

The next step was the selection of those stand variables most valuable for predicting gross cubic volume. A graphical analysis indicated that field-measured tree heights were more closely related to location volumes than any other single variable, including heights measured on aerial photographs. It was therefore decided that the former measurements should be used in the statistical tests, thus eliminating a degree of interpreter bias. Crown closure percent appeared to be the second-best variable and average crown diameter ranked third.

A wide span of values was exhibited by each group of stand measurements. Field heights ranged from 23 to 123 feet, crown closures from 5 to 90 percent, crown diameters from 5 to 28 feet, and gross volumes from 15 to 3,880 cubic feet per acre.

Several additional variables were formulated from combinations of the 3 basic measurements. The 9 chosen for regression analysis[4] are as follows:

1. Height
2. Crown closure percent
3. Height × crown closure
4. $(\text{Height})^2$
5. $(\text{Height})^2$ × crown closure
6. Height × $(\text{crown closure})^2$
7. Crown diameter × crown closure
8. Crown diameter × height
9. $(\text{Crown diameter})^2$ × height

The objective was to obtain the degree of correlation between these 9 variables and the gross cubic volume per acre as determined from Forest Survey field measurements.

Data were analyzed by the Southern Forest Experiment Station's IBM 704 Regression Program (6). From the 511 regressions computed, this 5-variable equation[5] was selected as best for compiling the aerial volume table:

$$V = 939.065 + 1.258\ HC + 0.426\ H^2 - 39.358\ C - 34.155\ H - 0.007\ H^2C,$$ where:

V = Gross volume per acre in cubic feet.

H = Average total height of the 3 tallest trees in feet.

C = Crown closure percent of all trees over 30 feet tall.

This equation includes only the first 5 of the 9 variables analyzed. Average total height proved to be the most valuable single variable for predicting gross stand volume, as illustrated by its presence in 4 terms of the regression. Crown closure percent, included in 3 terms, was of secondary value. As none of the variables involving crown diameter contributed significantly to the prediction of volume, they were eliminated from the formula.

Because of the importance of tree height, the composite aerial volume table (table 1) was compiled by 5-foot height classes. Ten-percent intervals were maintained for crown closure, though linear interpolations may be made between classes, if desired.

PHOTO INTERPRETATION TECHNIQUES

Crown closure estimates.—Of the two variables required to enter table 1, crown closure percent[6] is the more difficult to evaluate accurately and consistently. As there are no practical means for objectively measuring this characteristic on 1:20,000 photographs, ocular estimates are relied upon. Stands are usually stratified into 10-percent closure classes by comparing the stereo-image with printed density scales (**1**, **9**).

The heavy dependence on personal judgment can result in widely divergent estimates when a location is assessed by 2 or more interpreters. In such instances, an arithmetic average can be used. Inexperienced persons tend to overestimate crown closure, often failing to make proper allowance for small stand openings, crown shadows, or trees too small to contain merchantable volume. For applying the composite table, crown closure esti-

[4] The term "height" used here refers to the average total height of the 3 tallest trees as measured on the ground. Crown closures and crown diameters are photographic determinations.

[5] Multiple correlation coefficient is + 0.834. Standard error of estimate is 436.6 cubic feet.

[6] The proportion of the forest canopy occupied by tree crowns; also referred to as crown cover percent or crown density.

Table 1.—*Composite aerial volume table for southern Arkansas*

Average total height[1] (feet)	Crown closure									
	5 percent	15 percent	25 percent	35 percent	45 percent	55 percent	65 percent	75 percent	85 percent	95 percent
	Gross cubic feet per acre[2]									
40	175	215	250	290	325	365	400	440	475	515
45	240	295	345	400	450	505	555	610	660	715
50	330	395	460	525	590	655	720	790	855	920
55	395	490	580	675	765	860	950	1,045	1,140	1,230
60	480	600	715	830	950	1,065	1,180	1,300	1,415	1,530
65	585	725	860	1,000	1,135	1,275	1,410	1,545	1,685	1,820
70	715	865	1,020	1,175	1,330	1,480	1,635	1,790	1,945	2,100
75	860	1,025	1,195	1,360	1,530	1,695	1,865	2,030	2,200	2,365
80	1,020	1,200	1,380	1,555	1,735	1,910	2,090	2,270	2,445	2,625
85	1,205	1,390	1,575	1,760	1,945	2,130	2,315	2,500	2,685	2,870
90	1,410	1,600	1,785	1,975	2,165	2,350	2,540	2,730	2,915	3,105
95	1,635	1,820	2,010	2,200	2,385	2,575	2,765	2,950	3,140	3,330
100	1,875	2,060	2,245	2,430	2,615	2,800	2,985	3,170	3,355	3,540
105	2,140	2,315	2,495	2,675	2,850	3,030	3,210	3,385	3,565	3,745
110	2,420	2,590	2,755	2,925	3,095	3,260	3,430	3,600	3,765	3,935
115	2,725	2,880	3,030	3,185	3,340	3,495	3,650	3,805	3,960	4,115
120	3,045	3,180	3,320	3,455	3,595	3,730	3,870	4,005	4,145	4,280

[1] As the table is based on field measurements of tree heights, photo heights must be adjusted as explained in the following section.

[2] Gross volumes are inside bark and include the merchantable stems of all live trees 5 inches d.b.h. and larger from stump to a variable top diameter not smaller than 4 inches i. b.

mates should include only those trees that are taller than 30 feet. Crowns of shorter trees should be ignored, as they presumably represent stems smaller than 5 inches d.b.h.

Height measurements and parallax conversion. — Tree heights can be determined within ± 5 to 10 feet on aerial photographs from stereoscopic measurements of differential parallax (dP). Two basic types of floating dot instruments are used for this purpose: parallax wedges reading to 0.002-inch dP, and parallax bars reading to 0.01-millimeter dP. Measurements with either device are converted to tree heights by substitution in the parallax formula:

$$ho = \frac{H \times dP}{P + dP}, \text{ where:}$$

ho = height of object
H = height of aircraft above ground datum
P = average photo base length
dP = differential parallax

If object heights are to be determined in feet, the height of the photographing aircraft must also be expressed in feet. Average photo base length (P) and differential parallax (dP) may be expressed either in inches or millimeters, but both must be in the same units. Solution of the formula is not difficult, but conversion of parallax readings can be simplified by use of special tables. For example, table 2 was prepared for quickly converting parallax-bar readings to tree heights in feet. A similar table is available for converting parallax wedge measurements (8).

To apply table 2, the interpreter must make three determinations:

a. **Differential parallax** of the tree or object, measured with a parallax bar (fig. 2) and recorded to the nearest hundredth of a millimeter. For use with the composite aerial volume table, height measurements should represent an average for 3 to 5 of the tallest trees on the acre.

b. **Average photo base** for the stereo-pair. This corresponds to the average distance between principal and conjugate principal points. It should be measured with an engineer's scale and recorded to the nearest 0.1 inch (conversion to millimeters was accounted for in constructing the table).

c. **Average flying height of aircraft**, determined by multiplying the photo scale denominator by the camera's focal length in feet. For example, if photo scale in the area of measurement is 1:19,000 and camera focal

Table 2.—*Parallax-bar height conversion factors*[1]

Average photo base (P)	Average flying height (H) above ground datum in feet								
	2,500	3,000	3,500	4,000	4,500	5,000	5,500	6,000	6,500
Inches	— — — — *Object heights (ho) in feet per millimeter* — — — —								
2.1	46	55	64	74	83	92	101	110	120
2.2	44	53	62	70	79	88	97	105	114
2.3	42	50	59	67	76	84	93	101	109
2.4	40	48	56	65	73	81	89	97	105
2.5	39	47	54	62	70	78	85	93	101
2.6	37	45	52	60	67	75	82	90	97
2.7	36	43	50	57	65	72	79	86	93
2.8	35	42	49	55	62	69	76	83	90
2.9	33	40	47	54	60	67	74	80	87
3.0	32	39	45	52	58	65	71	78	84
3.1	31	38	44	50	56	63	69	75	82
3.2	30	36	43	49	55	61	67	73	79
3.3	29	35	41	47	53	59	65	71	77
3.4	29	34	40	46	51	57	63	69	74
3.5	28	33	39	44	50	56	61	67	72
3.6	27	32	38	43	49	54	60	65	70
3.7	26	32	37	42	47	53	58	63	68
3.8	26	31	36	41	46	51	56	62	67
3.9	25	30	35	40	45	50	55	60	65
4.0	24	29	34	39	44	49	54	58	63
4.1	24	29	33	38	43	48	52	57	62
4.2	23	28	32	37	42	46	51	56	60
4.3	23	27	32	36	41	45	50	54	59
4.4	22	27	31	35	40	44	49	53	58
4.5	22	26	30	35	39	43	48	52	56

Average photo base (P)	Average flying height (H) above ground datum in feet								
	11,500	12,000	12,500	13,000	13,500	14,000	14,500	15,000	15,500
Inches	— — — — *Object heights (ho) in feet per millimeter* — — — —								
2.1	212	221	230	239	249	258	267	276	285
2.2	202	211	220	228	237	246	255	264	272
2.3	194	202	210	219	227	236	244	253	261
2.4	185	194	202	210	218	226	234	242	250
2.5	178	186	194	202	209	217	225	256	264
2.6	172	179	187	194	201	209	216	224	231
2.7	165	172	180	187	194	201	208	216	223
2.8	159	166	173	180	187	194	201	208	215
2.9	154	161	167	174	181	187	194	201	207
3.0	149	155	162	168	175	181	188	194	201
3.1	144	151	157	163	169	176	182	188	194
3.2	140	146	152	158	164	170	176	182	188
3.3	136	142	147	153	159	165	171	177	183
3.4	132	137	143	149	154	160	166	172	177
3.5	128	133	139	145	150	156	161	167	172
3.6	124	130	135	141	146	152	157	162	168
3.7	121	126	132	137	142	147	153	158	163
3.8	118	123	128	133	138	144	149	154	159
3.9	115	120	125	130	135	140	145	150	155
4.0	112	117	122	127	132	136	141	146	151
4.1	109	114	119	124	128	133	138	143	147
4.2	107	111	116	121	125	130	135	139	144
4.3	104	109	113	118	123	127	132	136	141
4.4	102	106	111	115	120	124	129	133	137
4.5	100	104	108	113	117	121	126	130	134

[1] To use table, measure parallax difference (dP) of object to nearest hundredth of a millimeter (as 0.41 mm, for example). If average photo base (P) is 3.1 inches and flying height (H) is

Average flying height (H) above ground datum in feet									Average photo base (P)
7,000	7,500	8,000	8,500	9,000	9,500	10,000	10,500	11,000	
Object heights (ho) in feet per millimeter									*Inches*
129	138	147	157	166	175	184	193	203	2.1
123	132	141	149	158	167	176	185	193	2.2
118	126	135	143	152	160	168	177	185	2.3
113	121	129	137	145	153	161	169	177	2.4
109	116	124	132	140	147	155	163	171	2.5
104	112	119	127	134	142	149	157	164	2.6
101	108	115	122	129	136	144	151	158	2.7
97	104	111	118	125	132	139	146	153	2.8
94	100	107	114	120	127	134	141	147	2.9
91	97	104	110	117	123	130	136	142	3.0
88	94	100	107	113	119	125	132	138	3.1
85	91	97	103	109	115	122	128	134	3.2
83	88	94	100	106	112	118	124	130	3.3
80	86	92	97	103	109	114	120	126	3.4
78	83	89	95	100	106	111	117	122	3.5
76	81	87	92	97	103	108	114	119	3.6
74	79	84	89	95	100	105	111	116	3.7
72	77	82	87	92	97	103	108	113	3.8
70	75	80	85	90	95	100	105	110	3.9
68	73	78	83	88	93	97	102	107	4.0
67	71	76	81	86	90	95	100	105	4.1
65	70	74	79	84	88	93	97	102	4.2
64	68	73	77	82	86	91	95	100	4.3
62	66	71	75	80	84	89	93	98	4.4
61	65	69	74	78	82	87	91	95	4.5

Average flying height (H) above ground datum in feet									Average photo base (P)
16,000	16,500	17,000	17,500	18,000	18,500	19,000	19,500	20,000	
Object heights (ho) in feet per millimeter									*Inches*
295	304	313	322	331	341	350	359	368	2.1
281	290	299	308	316	325	334	343	352	2.2
269	278	286	295	303	311	320	328	337	2.3
258	266	274	282	290	298	306	315	323	2.4
248	256	264	271	279	287	295	302	310	2.5
239	246	254	261	269	276	284	291	298	2.6
230	237	244	251	259	266	273	280	287	2.7
222	229	236	243	250	257	264	270	277	2.8
214	221	228	234	241	248	254	261	268	2.9
207	214	220	227	233	240	246	253	259	3.0
201	207	213	220	226	232	238	245	251	3.1
194	200	207	213	219	225	231	237	243	3.2
189	195	200	206	212	218	224	230	236	3.3
183	189	194	200	206	212	217	223	229	3.4
178	184	189	195	200	206	211	217	222	3.5
173	179	184	189	195	200	206	211	216	3.6
168	174	179	184	189	195	200	205	211	3.7
164	169	174	179	185	190	195	200	205	3.8
160	165	170	175	180	185	190	195	200	3.9
156	161	166	171	175	180	185	190	195	4.0
152	157	162	167	171	176	181	186	190	4.1
149	153	158	162	167	172	176	181	186	4.2
145	150	154	159	163	168	172	177	181	4.3
142	146	151	155	160	164	168	173	177	4.4
139	143	147	152	156	160	165	169	173	4.5

15,000 feet, the conversion factor of 188 is multiplied by 0.41 for an object height of 77 feet. Linear interpolations may be made in the table for determining conversion factors not shown.

length is six inches, H = 19,000 × 0.5 or 9,500 feet.

Thus, if P = 3.2 inches and H = 9,500 feet, the conversion factor of 115 is read from table 2 and multiplied by dP (as 0.44 mm, for example) for a height of 51 feet.

Table 2 may be safely applied only when dP is small with relation to P. With ordinary 9- by 9-inch aerial photos and an average overlap of 60 percent, the ratio of dP to P is 1:100 or smaller. If the ratio becomes as large as 1:50, however, values should be substituted directly in the parallax formula.

The range of photo base lengths used in compiling this table (2.1 to 4.5 inches) was chosen on the assumption that the table would be used with 7- by 7-, 7- by 9-, or 9- by 9-inch aerial prints having an average forward overlap of 50 to 70 percent. The range of flying heights above ground (2,500 to 20,000 feet) covers photo scales from 1:2,500 to 1:40,000, assuming use of cameras with 12- and 6-inch focal lengths, respectively.

Individual adjustments of photo heights.—The composite aerial volume table (table 1) was based on field-measured tree heights. As individuals may differ widely in determining heights on aerial photos, each interpreter should make his own corrections for converting photo heights to actual tree heights. This can be done as follows:

Select 15 or more trees within the area to be interpreted, and determine their total heights by ground measurement. These sample trees should span a wide range of heights and be readily identifiable on the aerial photographs.

Measure each sample tree at least three times to determine its average photo height. On cross-section paper, plot field heights over photo heights, and fit a line to the plotted points by either the graphical or least squares method.

Use the graph to correct all subsequent photo height determinations prior to entering the aerial volume table.

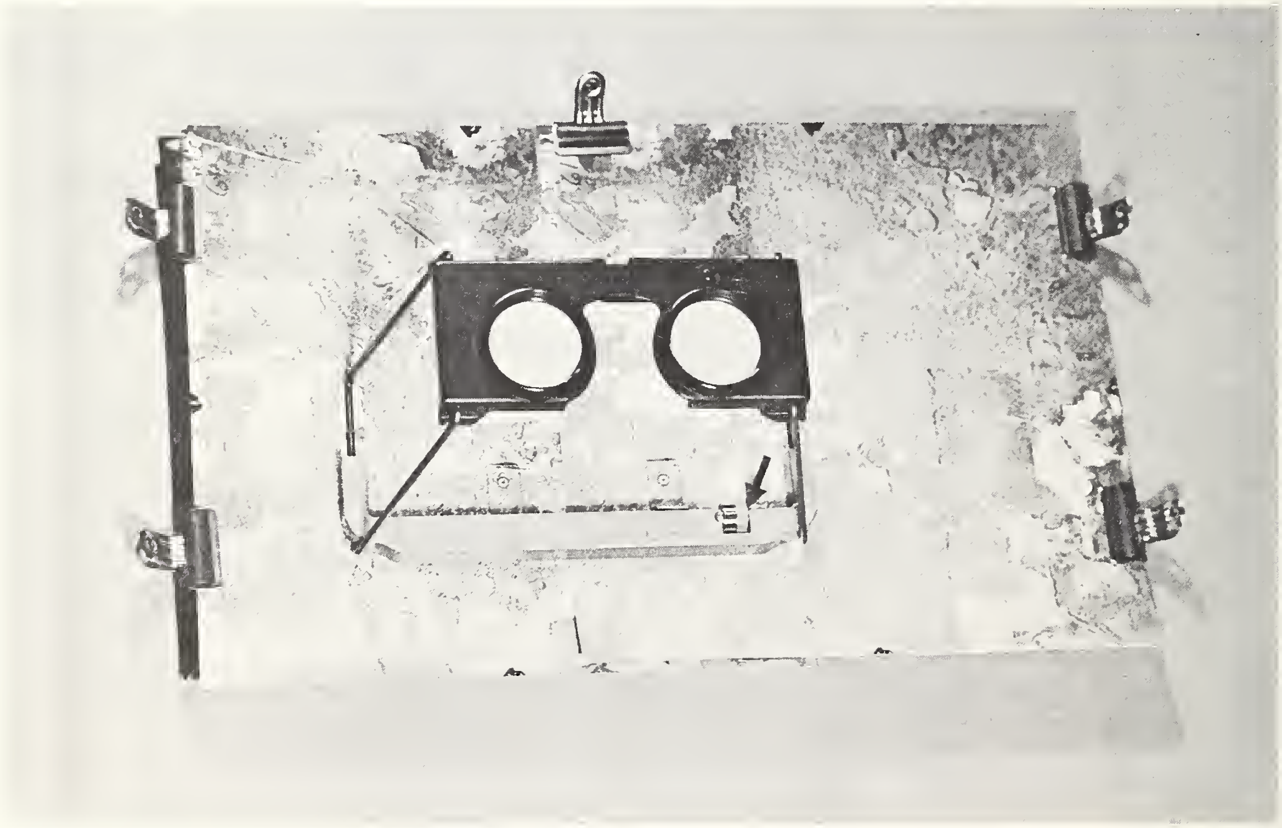

Figure 2.—*Abrams parallax bar used for making stereoscopic determinations of tree heights. Differential parallax readings in millimeters can be converted to feet by reference to table 2.*

DIRECT ESTIMATES OF GROSS VOLUME

The accuracy of aerial timber estimates depends on the scale and quality of available photography, the ability of photo interpreters to make required stand measurements, and the statistical reliability of the aerial volume table. Even when these circumstances are favorable, individual location volumes can rarely be determined with precision. However, reliable estimates of average volume per acre may be obtained by interpreting large numbers of locations.

Field check 1.—One hundred additional Survey locations in southern Arkansas were selected for evaluation by two interpreters. Each man made independent determinations of cubic volume for the 100 locations by entering the composite aerial volume table. Neither interpreter had participated in the collection of field data, and actual volumes were unknown. Photo and field comparisons of average volume per acre are presented in table 3.

Estimates by both interpreters showed good agreement with average field volumes. On the first 50 locations, the maximum interpreter error was minus 16 percent; for the second group, the greatest deviation was plus 17 percent. For each interpreter, negative differences on the first 50 locations were compensated by higher readings on the second set of 50 measurements. When the 100-location averages were used for comparison, interpreter errors decreased to less than 3 percent of the average field volume per acre.

Comparison for individual locations were much more erratic than the checks of average volumes. Photo estimates occasionally differed by 75 to 90 percent from field values. Such variations were not unexpected, however, as the standard error of estimates for the composite table was 437 cubic feet, or about 45 percent of the mean field volume. Some disagreements between individual estimates can be attributed to the fact that photo measurements were made on 1-acre circular plots, while field volumes were determined from 2 point-samples spaced 117.75 feet apart at each ground location.

Field check 2.—To further evaluate the composite aerial volume table, two 160-acre tracts in southern Arkansas were chosen for a comparison of photo and field cruises on small ownerships. Tract 1 had a predominant forest cover of loblolly-shortleaf pines and tract 2 was in a stand of mixed pines and upland hardwoods. A transparent template was used to locate 32 one-acre plots on 1:15,840 infrared photographs of each tract. These circular sample areas were mechanically spaced at 5- by 10-chain intervals. Two interpreters determined the volume of each plot by use of table 1. Average per-acre volumes were then multiplied by tract areas to obtain estimates of total gross volume for each tract. As in the previous test, field volumes were determined by point-sampling (5). Tree tallies were made at 80 points systematically located within each tract. A wedge prism having a basal area factor of 10 square feet per acre was used to select sample trees for measurement.

Photo and field estimates of total cubic volume for the 2 tracts are summarized in table 4. The relatively small interpreter errors again demonstrate the feasibility of aerial timber cruising. All photo estimates were within 12 percent of field values. This improvement in interpreter accuracy over the previous check (table 3) is partly due to the fact that the forest on the two 160-acre tracts was relatively homogeneous and even-aged, while the 100 Forest Survey locations encompassed a much wider range of stand-size classes.

Table 3.—*Comparison of average volumes from 100 Forest Survey locations with photo estimates by two interpreters*

Number of locations [1]	Average field volume per acre	Interpreter A		Interpreter B	
		Volume per acre	Error [2]	Volume per acre	Error [2]
	Cubic feet	*Cubic feet*	*Percent*	*Cubic feet*	*Percent*
1-50	1,544	1,297	−16.0	1,430	− 7.4
51-100	1,101	1,288	+17.0	1,254	+13.9
All 100	1,323	1,293	− 2.3	1,342	+ 1.4

[1] Randomly selected from 20 counties in southern Arkansas.
[2] Difference between photo and field volume expressed as a percent of field volume.

Another factor was the availability of better aerial photographs for the small tracts. Infrared prints at a scale of 1:15,840 were supplied by The Crossett Company for this check, while the previous analysis required the use of 1:20,000 panchromatic photographs.

Ordinarily, it is inadvisable to rely strictly on aerial-photo determinations. Prior to computation of total tract volumes, 5 to 10 percent of the photo plots should be field-checked to derive local per-acre correction factors (1). Such corrections not only improve the reliability of the final estimate, but also increase its acceptability to persons unfamiliar with aerial cruising techniques.

Aerial timber cruising cannot be expected to replace ground work for obtaining detailed breakdowns of tree species, diameter classes, growth, cull, and mortality. Thus, airphoto and field techniques are ordinarily not mutually exclusive alternatives. Instead, the advantages of both methods are logically combined in a forest inventory design that has greater efficiency than either approach considered singly (3).

As aerial volume tables are occasionally applicable outside the areas for which they were originally constructed, the authors would be interested in hearing from users of the composite table, particularly those in east Texas, north Louisiana, and central Mississippi. Applications in these areas should be feasible, provided local adjustments are derived by field checks.

Table 4.—*Comparison of photo and field volumes for two 160-acre forest tracts in southern Arkansas*

Tract	Total field volume [1]	Interpreter A		Interpreter B	
		Volume [1]	Error [2]	Volume [1]	Error [2]
	Cubic feet	*Cubic feet*	*Percent*	*Cubic feet*	*Percent*
Mixed loblolly-shortleaf pines	336,480	361,600	+ 7.5	376,000	+11.7
Mixed pines and hardwoods	342,720	305,600	−10.8	311,200	− 9.2

[1] Tract volumes may be converted to rough cords by dividing by 79.

[2] Difference between photo and field volumes expressed as a percent of field volume.

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